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Bramstedt, Karina

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## PARTNERING ETHICS AND CHEMISTRY IN SECONDARY AND UNIVERSITY STEM EDUCATION VIA AN INNOVATIVELY DESIGNED PERIODIC TABLE OF CHEMICAL ELEMENTS

Karina Bramstedt<sup>1</sup>

**Abstract:** As declared by the United Nations, 2019 is the International Year of the Periodic Table of Chemical Elements. Accordingly, an innovative new Periodic Table of Chemical Elements and Ethics [PETE] has been developed as an educational tool for secondary and university STEM (Science, Technology, Engineering and Mathematics) education. The tool is designed to be used in a case-based approach that is feasible to both individual and small group learners. Specifically, with the new periodic table, STEM becomes aligned with STSE (Science and Technology on Society and Environment), laying a curricular pathway for integrating discussions of ethics into the teaching of chemistry. Presented is the table, as well as sources for pairable ethics cases, and guidance for teachers to create curriculum which facilitates connections between ethics, chemistry, and society.

**Keywords** chemistry; education; ethics; science/education; educational technology

### **Ética y química asociadas en la educación secundaria y universitaria STEM, a través de una tabla periódica de elementos químicos de diseño innovador**

**Resumen:** Según lo declarado por las Naciones Unidas, 2019 es el Año Internacional de la Tabla Periódica de Elementos Químicos. En consecuencia, se ha desarrollado una nueva tabla periódica innovadora de elementos químicos y ética [PETE] como una herramienta educativa para la educación secundaria y universitaria STEM (Ciencia, Tecnología, Ingeniería y Matemáticas). La herramienta está diseñada para usarse en un enfoque basado en casos que sea factible tanto para estudiantes individuales como para grupos pequeños. Específicamente, con la nueva tabla periódica, STEM se alinea con STSE (Ciencia y Tecnología en Sociedad y Medio Ambiente), estableciendo una vía curricular para integrar las discusiones de ética en la enseñanza de la química. Se presenta la tabla, así como las fuentes de casos éticos deseables y orientación para que los maestros creen un plan de estudios que facilite las conexiones entre la ética, la química y la sociedad.

**Palabras clave:** química; educación; ética; enseñanza de las ciencias; tecnología Educativa

### **Associando ética e química na educação stem secundária e universitária via uma tabela periódica de elementos químicos desenvolvida de forma inovadora**

**Resumo:** Como declarado pelas Nações Unidas, 2019 é o Ano Internacional da Tabela Periódica de Elementos Químicos. Portanto, uma inovadora e nova Tabela Periódica de Elementos Químicos e Ética (PETE, sigla em inglês) foi desenvolvida como uma ferramenta educacional para educação STEM (sigla em inglês para Ciência, Tecnologia, Engenharia e Matemática) secundária e universitária. A ferramenta é elaborada para ser usada em uma abordagem baseada em casos, viável tanto para aprendizagem individual como de pequenos grupos. Especificamente, com a nova tabela periódica, STEM se alinha com STSE (sigla em inglês para Ciência e Tecnologia na Sociedade e Ambiente), estabelecendo uma via curricular para integrar discussões de ética no ensino de química. Apresenta-se a tabela, bem como fontes de casos éticos pareados, e orientação para professores criarem um currículo que facilite conexões entre ética, química e sociedade.

**Palavras chave:** química, educação, ética, ciência/educação, tecnologia educacional

<sup>1</sup> Luxembourg Agency for Research Integrity (LARI) 6, Luxembourg. Bond University Faculty of Medicine and Health Sciences, Queensland, Australia

**Correspondence:** txbioethics@yahoo.com

## Introduction

In 2016, Dr Astrid Steele argued in *The Journal of Science Teacher Education* that there was the “need for a moral component for science education”(1:357). She further stated that an ethical framework would “inform decisions and directions of [STEM] teachers, and teacher educators”(1:359). Concurring, an innovative new design of the Periodic Table of Chemical Elements has been created which facilitates both ethics and chemistry education in secondary schools as well as universities (Figure 1). Specifically, with the new periodic table, STEM content aligns with STSE (Science and Technology on Society and Environment) content, facilitating a curricular pathway to integrate discussions of ethics into the teaching of chemistry. 2019 was declared the International Year of the Periodic Table of Chemical Elements by the United Nations(2), thus the timely creation of this new table for STEM is fitting [See next page].

## The Evolution of the Periodic Table of Chemical Elements

What is known today as the Periodic Table of Chemical Elements had its origination in the mid-1800s by several scientists, including chemist Dmitri Ivanovich Mendeleev and physician Julius Lothar Meyer. Even the contributions and ultimate authorship credit of the table is an ethical issue worthy of debate(3). Due to the table’s unique ability to be a visual teaching tool, many variations have been created. These variations are notably different from the original in that they do not aim to also teach chemistry concurrently, but rather the Periodic Table of Chemical Elements becomes only a geometric template with the chemistry content removed. Such examples include the Periodic Table of the Presidents (<https://periodicpresidents.com/product/ptotp/>), Periodic Table of Figures of Speech (<https://visual.ly/community/infographic/education/periodic-table-figures-speech>), and the Periodic Table of Musical Instruments (<https://www.kickstarter.com/projects/1913274728/periodic-table-of-musical-instruments>).

## Meet PETE

Presented here is a newly designed Periodic Table

of Chemical Elements termed the **Periodic Table of Chemical Elements and Ethics [PETE.]** PETE retains the standard features of the Periodic Table of Chemical Elements(4) (i.e., atomic number, element symbol, element name, atomic mass) while pairing one word relating to ethics or research ethics along with the chemical element. The word pairing aligns to the letters of the element symbol (118 unique pairs). In this way, the geometric layout and scientific content of the Periodic Table of Chemical Elements are retained and visually intact, and the ethics content is added.

Some of the word-element pairs have an immediate ethical connection. For example, potassium (element 19, symbol K) is paired with the ethics word “kind”. In this context, students could explore the case of three authors who unkindly plagiarized the work of others who had also researched potassium(5). With regard to element 98 (Californium, symbol Cf), this is paired with the ethics word “confidentiality” and students could explore the National Aeronautics and Space Administration’s Aviation Safety Reporting System(6) in the context of Californium’s use in the detection of aircraft metal fatigue. Copper (element 29, symbol Cu) is paired with the ethics word “culture” and this can be explored in the context of mining harms to indigenous peoples(7). For the word-element pairings that do not [currently] have direct ethical connections, analysis of the pairings in the context of element groups and historical cases is proposed.

Teaching chemistry involves exploring the chemical elements according to their group (vertical column of elements that generally have similar physical and chemical properties), period (horizontal row of elements that have the same number of atomic orbitals), and blocks (table segments relating to electrons). Table 1 collates the ethics words according to element group to facilitate a potential curricular package that can further pair with a chemistry-related ethics case(8) that either the teacher presents for analysis, or that the students search for using the Internet as part of an individual or small group project. Reflective writing could also be added in addition to case discussions(9). Online sources for case studies are presented in Table 2.

Periodic Table of Chemical Elements and Ethics (PETE)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.00794	2 He Helium 4.002602	3 Li Lithium 6.941	4 Be Beryllium 9.0122	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180	11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.63	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.905	58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.5	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.967	72 Hf Hafnium 178.49
73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium 209	85 At Astatine 210	86 Rn Radon 222	87 Fr Francium 223	88 Ra Radium 226	89 Ac Actinium 227	90 Th Thorium 232
91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium 244	95 Am Americium 243	96 Cm Curium 247	97 Bk Berkelium 247	98 Cf Californium 251	99 Es Einsteinium 252	100 Fm Fermium 257	101 Md Mendelevium 258	102 No Nobelium 259	103 Lr Lawrencium 262	104 Rf Rutherfordium 261	105 Db Dubnium 262	106 Sg Seaborgium 266	107 Bh Bohrium 264	108 Hs Hassium 277
109 Mt Meitnerium 268	110 Ds Darmstadtium 271	111 Rg Roentgenium 272	112 Cn Copernicium 285	113 Nh Nihonium 284	114 Fl Flerovium 289	115 Mc Moscovium 288	116 Lv Livermorium 293	117 Ts Tennessine 294	118 Og Oganesson 294	119 Uut Ununtrium 295	120 Uub Ununbium 296	121 Uuq Ununquadium 297	122 Uuh Ununhexium 298	123 Uus Ununseptium 299	124 Uuo Ununoctium 300	125 Uut Ununtrium 301	126 Uuq Ununquadium 302
127 Uus Ununseptium 303	128 Uuo Ununoctium 304	129 Uut Ununtrium 305	130 Uuq Ununquadium 306	131 Uuh Ununhexium 307	132 Uus Ununseptium 308	133 Uuo Ununoctium 309	134 Uut Ununtrium 310	135 Uuq Ununquadium 311	136 Uuh Ununhexium 312	137 Uus Ununseptium 313	138 Uuo Ununoctium 314	139 Uut Ununtrium 315	140 Uuq Ununquadium 316	141 Uuh Ununhexium 317	142 Uus Ununseptium 318	143 Uuo Ununoctium 319	144 Uut Ununtrium 320
145 Uub Ununbium 321	146 Uut Ununtrium 322	147 Uuq Ununquadium 323	148 Uuh Ununhexium 324	149 Uus Ununseptium 325	150 Uuo Ununoctium 326	151 Uut Ununtrium 327	152 Uuq Ununquadium 328	153 Uuh Ununhexium 329	154 Uus Ununseptium 330	155 Uuo Ununoctium 331	156 Uut Ununtrium 332	157 Uuq Ununquadium 333	158 Uuh Ununhexium 334	159 Uus Ununseptium 335	160 Uuo Ununoctium 336	161 Uut Ununtrium 337	162 Uuq Ununquadium 338
163 Uub Ununbium 339	164 Uut Ununtrium 340	165 Uuq Ununquadium 341	166 Uuh Ununhexium 342	167 Uus Ununseptium 343	168 Uuo Ununoctium 344	169 Uut Ununtrium 345	170 Uuq Ununquadium 346	171 Uuh Ununhexium 347	172 Uus Ununseptium 348	173 Uuo Ununoctium 349	174 Uut Ununtrium 350	175 Uuq Ununquadium 351	176 Uuh Ununhexium 352	177 Uus Ununseptium 353	178 Uuo Ununoctium 354	179 Uut Ununtrium 355	180 Uuq Ununquadium 356
181 Uub Ununbium 357	182 Uut Ununtrium 358	183 Uuq Ununquadium 359	184 Uuh Ununhexium 360	185 Uus Ununseptium 361	186 Uuo Ununoctium 362	187 Uut Ununtrium 363	188 Uuq Ununquadium 364	189 Uuh Ununhexium 365	190 Uus Ununseptium 366	191 Uuo Ununoctium 367	192 Uut Ununtrium 368	193 Uuq Ununquadium 369	194 Uuh Ununhexium 370	195 Uus Ununseptium 371	196 Uuo Ununoctium 372	197 Uut Ununtrium 373	198 Uuq Ununquadium 374
199 Uub Ununbium 375	200 Uut Ununtrium 376	201 Uuq Ununquadium 377	202 Uuh Ununhexium 378	203 Uus Ununseptium 379	204 Uuo Ununoctium 380	205 Uut Ununtrium 381	206 Uuq Ununquadium 382	207 Uuh Ununhexium 383	208 Uus Ununseptium 384	209 Uuo Ununoctium 385	210 Uut Ununtrium 386	211 Uuq Ununquadium 387	212 Uuh Ununhexium 388	213 Uus Ununseptium 389	214 Uuo Ununoctium 390	215 Uut Ununtrium 391	216 Uuq Ununquadium 392
217 Uub Ununbium 393	218 Uut Ununtrium 394	219 Uuq Ununquadium 395	220 Uuh Ununhexium 396	221 Uus Ununseptium 397	222 Uuo Ununoctium 398	223 Uut Ununtrium 399	224 Uuq Ununquadium 400	225 Uuh Ununhexium 401	226 Uus Ununseptium 402	227 Uuo Ununoctium 403	228 Uut Ununtrium 404	229 Uuq Ununquadium 405	230 Uuh Ununhexium 406	231 Uus Ununseptium 407	232 Uuo Ununoctium 408	233 Uut Ununtrium 409	234 Uuq Ununquadium 410
237 Uub Ununbium 411	238 Uut Ununtrium 412	239 Uuq Ununquadium 413	240 Uuh Ununhexium 414	241 Uus Ununseptium 415	242 Uuo Ununoctium 416	243 Uut Ununtrium 417	244 Uuq Ununquadium 418	245 Uuh Ununhexium 419	246 Uus Ununseptium 420	247 Uuo Ununoctium 421	248 Uut Ununtrium 422	249 Uuq Ununquadium 423	250 Uuh Ununhexium 424	251 Uus Ununseptium 425	252 Uuo Ununoctium 426	253 Uut Ununtrium 427	254 Uuq Ununquadium 428
257 Uub Ununbium 429	258 Uut Ununtrium 430	259 Uuq Ununquadium 431	260 Uuh Ununhexium 432	261 Uus Ununseptium 433	262 Uuo Ununoctium 434	263 Uut Ununtrium 435	264 Uuq Ununquadium 436	265 Uuh Ununhexium 437	266 Uus Ununseptium 438	267 Uuo Ununoctium 439	268 Uut Ununtrium 440	269 Uuq Ununquadium 441	270 Uuh Ununhexium 442	271 Uus Ununseptium 443	272 Uuo Ununoctium 444	273 Uut Ununtrium 445	274 Uuq Ununquadium 446
277 Uub Ununbium 449	278 Uut Ununtrium 450	279 Uuq Ununquadium 451	280 Uuh Ununhexium 452	281 Uus Ununseptium 453	282 Uuo Ununoctium 454	283 Uut Ununtrium 455	284 Uuq Ununquadium 456	285 Uuh Ununhexium 457	286 Uus Ununseptium 458	287 Uuo Ununoctium 459	288 Uut Ununtrium 460	289 Uuq Ununquadium 461	290 Uuh Ununhexium 462	291 Uus Ununseptium 463	292 Uuo Ununoctium 464	293 Uut Ununtrium 465	294 Uuq Ununquadium 466
297 Uub Ununbium 469	298 Uut Ununtrium 470	299 Uuq Ununquadium 471	300 Uuh Ununhexium 472	301 Uus Ununseptium 473	302 Uuo Ununoctium 474	303 Uut Ununtrium 475	304 Uuq Ununquadium 476	305 Uuh Ununhexium 477	306 Uus Ununseptium 478	307 Uuo Ununoctium 479	308 Uut Ununtrium 480	309 Uuq Ununquadium 481	310 Uuh Ununhexium 482	311 Uus Ununseptium 483	312 Uuo Ununoctium 484	313 Uut Ununtrium 485	314 Uuq Ununquadium 486
317 Uub Ununbium 489	318 Uut Ununtrium 490	319 Uuq Ununquadium 491	320 Uuh Ununhexium 492	321 Uus Ununseptium 493	322 Uuo Ununoctium 494	323 Uut Ununtrium 495	324 Uuq Ununquadium 496	325 Uuh Ununhexium 497	326 Uus Ununseptium 498	327 Uuo Ununoctium 499	328 Uut Ununtrium 500	329 Uuq Ununquadium 501	330 Uuh Ununhexium 502	331 Uus Ununseptium 503	332 Uuo Ununoctium 504	333 Uut Ununtrium 505	334 Uuq Ununquadium 506
337 Uub Ununbium 509	338 Uut Ununtrium 510	339 Uuq Ununquadium 511	340 Uuh Ununhexium 512	341 Uus Ununseptium 513	342 Uuo Ununoctium 514	343 Uut Ununtrium 515	344 Uuq Ununquadium 516	345 Uuh Ununhexium 517	346 Uus Ununseptium 518	347 Uuo Ununoctium 519	348 Uut Ununtrium 520	349 Uuq Ununquadium 521	350 Uuh Ununhexium 522	351 Uus Ununseptium 523	352 Uuo Ununoctium 524	353 Uut Ununtrium 525	354 Uuq Ununquadium 526
357 Uub Ununbium 529	358 Uut Ununtrium 530	359 Uuq Ununquadium 531	360 Uuh Ununhexium 532	361 Uus Ununseptium 533	362 Uuo Ununoctium 534	363 Uut Ununtrium 535	364 Uuq Ununquadium 536	365 Uuh Ununhexium 537	366 Uus Ununseptium 538	367 Uuo Ununoctium 539	368 Uut Ununtrium 540	369 Uuq Ununquadium 541	370 Uuh Ununhexium 542	371 Uus Ununseptium 543	372 Uuo Ununoctium 544	373 Uut Ununtrium 545	374 Uuq Ununquadium 546
377 Uub Ununbium 549	378 Uut Ununtrium 550	379 Uuq Ununquadium 551	380 Uuh Ununhexium 552	381 Uus Ununseptium 553	382 Uuo Ununoctium 554	383 Uut Ununtrium 555	384 Uuq Ununquadium 556	385 Uuh Ununhexium 557	386 Uus Ununseptium 558	387 Uuo Ununoctium 559	388 Uut Ununtrium 560	389 Uuq Ununquadium 561	390 Uuh Ununhexium 562	391 Uus Ununseptium 563	392 Uuo Ununoctium 564	393 Uut Ununtrium 565	394 Uuq Ununquadium 566
397 Uub Ununbium 569	398 Uut Ununtrium 570	399 Uuq Ununquadium 571	400 Uuh Ununhexium 572	401 Uus Ununseptium 573	402 Uuo Ununoctium 574	403 Uut Ununtrium 575	404 Uuq Ununquadium 576	405 Uuh Ununhexium 577	406 Uus Ununseptium 578	407 Uuo Ununoctium 579	408 Uut Ununtrium 580	409 Uuq Ununquadium 581	410 Uuh Ununhexium 582	411 Uus Ununseptium 583	412 Uuo Ununoctium 584	413 Uut Ununtrium 585	414 Uuq Ununquadium 586
417 Uub Ununbium 589	418 Uut Ununtrium 590	419 Uuq Ununquadium 591	420 Uuh Ununhexium 592	421 Uus Ununseptium 593	422 Uuo Ununoctium 594	423 Uut Ununtrium 595	424 Uuq Ununquadium 596	425 Uuh Ununhexium 597	426 Uus Ununseptium 598	427 Uuo Ununoctium 599	428 Uut Ununtrium 600	429 Uuq Ununquadium 601	430 Uuh Ununhexium 602	431 Uus Ununseptium 603	432 Uuo Ununoctium 604	433 Uut Ununtrium 605	434 Uuq Ununquadium 606
437 Uub Ununbium 609	438 Uut Ununtrium 610	439 Uuq Ununquadium 611	440 Uuh Ununhexium 612	441 Uus Ununseptium 613	442 Uuo Ununoctium 614	443 Uut Ununtrium 615	444 Uuq Ununquadium 616	445 Uuh Ununhexium 617	446 Uus Ununseptium 618	447 Uuo Ununoctium 619	448 Uut Ununtrium 620	449 Uuq Ununquadium 621	450 Uuh Ununhexium 622	451 Uus Ununseptium 623	452 Uuo Ununoctium 624	453 Uut Ununtrium 625	454 Uuq Ununquadium 626
457 Uub Ununbium 629	458 Uut Ununtrium 630	459 Uuq Ununquadium 631	460 Uuh Ununhexium 632	461 Uus Ununseptium 633	462 Uuo Ununoctium 634	463 Uut Ununtrium 635	464 Uuq Ununquadium 636	465 Uuh Ununhexium 637	466 Uus Ununseptium 638	467 Uuo Ununoctium 639	468 Uut Ununtrium 640	469 Uuq Ununquadium 641	470 Uuh Ununhexium 642	471 Uus Ununseptium 643	472 Uuo Ununoctium 644	473 Uut Ununtrium 645	474 Uuq Ununquadium 646
477 Uub Ununbium 649	478 Uut Ununtrium 650	479 Uuq Ununquadium 651	480 Uuh Ununhexium 652	481 Uus Ununseptium 653	482 Uuo Ununoctium 654	483 Uut Ununtrium 655	484 Uuq Ununquadium 656	485 Uuh Ununhexium 657	486 Uus Ununseptium 658	487 Uuo Ununoctium 659	488 Uut Ununtrium 660	489 Uuq Ununquadium 661	490 Uuh Ununhexium 662	491 Uus Ununseptium 663	492 Uuo Ununoctium 664	493 Uut Ununtrium 665	494 Uuq Ununquadium 666
497 Uub Ununbium 669	498 Uut Ununtrium 670	499 Uuq Ununquadium 671	500 Uuh Ununhexium 672	501 Uus Ununseptium 673	502 Uuo Ununoctium 674	503 Uut Ununtrium 675	504 Uuq Ununquadium 676	505 Uuh Ununhexium 677	506 Uus Ununseptium 678	507 Uuo Ununoctium 679	508 Uut Ununtrium 680	509 Uuq Ununquadium 681	510 Uuh Ununhexium 682	511 Uus Ununseptium 683	512 Uuo Ununoctium 684	513 Uut Ununtrium 685	514 Uuq Ununquadium 686
517 Uub Ununbium 689	518 Uut Ununtrium 690	519 Uuq Ununquadium 691	520 Uuh Ununhexium 692	521 Uus Ununseptium 693	522 Uuo Ununoctium 694	523 Uut Ununtrium 695	524 Uuq Ununquadium 696	525 Uuh Ununhexium 697	526 Uus Ununseptium 698	527 Uuo Ununoctium 699	528 Uut Ununtrium 700	529 Uuq Ununquadium 701	530 Uuh Ununhexium 702	531 Uus Ununseptium 703	532 Uuo Ununoctium 704	533 Uut Ununtrium 705	534 Uuq Ununquadium 706
537 Uub Ununbium 709	538 Uut Ununtrium 710	539 Uuq Ununquadium 711	540 Uuh Ununhexium 712	541 Uus Ununseptium 713	542 Uuo Ununoctium 714	543 Uut Ununtrium 715	544 Uuq Ununquadium 716	545 Uuh Ununhexium 717	546 Uus Ununseptium 718	547 Uuo Ununoctium 719	548 Uut Ununtrium 720	549 Uuq Ununquadium 721	550 Uuh Ununhexium 722	551 Uus Ununseptium 723	552 Uuo Ununoctium 724	553 Uut Ununtrium 725	554 Uuq Ununquadium 726
557 Uub Ununbium 729	558 Uut Ununtrium																

Table 1. Element Groups and the Ethics Terms/ Atomic Number

Group #	Ethics Terms
1	Hypothesis/1; Listen/3; Nature/11; Kind/19; Robust/37; Codes/55; Fair/87
2	Benefit/4; Mitigate/12; Careful/20; Scruples/38; Balance/56; Rapport/88
3	Secure/21; Yielding/39; Lawful/57; Cerebral/58; Proper/59; Need/60; Permission/61; Smile/62; Equipoise/63; Good/64; Timber/65; Duty/66; Honest/67; Earnest/68; Teamwork/69; Verifiability/70; Luminant/71; Accurate/89; Thank/90; Pauseful/91; Utility/92; Non-Partisan/93; Purpose/94; Amiable/95; Circumspect/96; Benchmark/97; Confidentiality/98; Ethos/99; Fathom/100; Methodical/101; Novel/102; Liberty/103
4	Timely/22; Zoiatrics/40; Helpful/72; Reference/104
5	Veracity/23; Noble/41; Tactful/73; Debrief/105
6	Credible/24; Moral/42; Worthy/74; Sporting/106
7	Manners/25; Toxicity/43; Reliable/75; Bioethics/107
8	Feedback/26; Rule/44; Onus/76; Humans/108
9	Collegial/27; Rights/45; Irenic/77; Mentored/109
10	Nice/28; Prudent/26; Patience/78; Disclose/110
11	Culture/29; Agile/47; Authorized/79; Regulated/111
12	(Grey) Zone/30; Credit/48; High Road/80; Consent/112
13	Bona Fide/5; Altruism/13; Gatekeeper/31; Insight/49; Truthful/81; Neighborly/113
14	Courage/6; Sincere/14; Genuine/32; Sound/50; Publish/82; Fly Right/114
15	Norm/7; Professional/15; Ask/33; Stable/51; Biosafety/83; Meticulous/115
16	Objective/8; Sharing/16; Search/34; Temperate/52; Polite/84; Level-headed/116
17	Futility/9; Clear/17; Belmont Report/35; Inclusion/53; Attentive/85; Trust/117
18	Humane/2; Neutral/10; Archive/18; Kindred/36; Xenial/54; Randomization/86; Obligation/118

Table 2. Online Sources for Chemistry-Ethics Case Studies

Source	Location
News stories	Google search (e.g., search terms chemist/chemistry, ethics/misconduct, lab/laboratory, poison)
Full journal articles discussing chemistry-ethics cases	<a href="http://www.hyle.org/journal/issues/special/ethical-cases.html">http://www.hyle.org/journal/issues/special/ethical-cases.html</a>
Fictional chemistry-ethics cases created by the American Chemical Society	<a href="https://www.acs.org/content/acs/en/about/governance/committees/ethics/ethics-case-studies.html">https://www.acs.org/content/acs/en/about/governance/committees/ethics/ethics-case-studies.html</a>
Fictional cases in e-book, chapter 7, <i>The Ethical Chemist</i>	<a href="https://global.oup.com/academic/product/the-ethical-chemist-9780190668648?cc=lu&amp;lang=en&amp;">https://global.oup.com/academic/product/the-ethical-chemist-9780190668648?cc=lu&amp;lang=en&amp;</a>
Catalogue of chemistry-related retracted journal articles	<a href="https://retractionwatch.com/category/by-subject/physical-sciences-retractions/chemistry-retractions/">https://retractionwatch.com/category/by-subject/physical-sciences-retractions/chemistry-retractions/</a>
Misconduct cases from the US Office of Research Integrity	<a href="https://ori.hhs.gov/content/case-summary-endo-matthew">https://ori.hhs.gov/content/case-summary-endo-matthew</a> <a href="https://ori.hhs.gov/content/case-summary-baughman-brandi-m">https://ori.hhs.gov/content/case-summary-baughman-brandi-m</a> <a href="https://ori.hhs.gov/content/case-summary-ramadugu-venkata-sudheer-kumar">https://ori.hhs.gov/content/case-summary-ramadugu-venkata-sudheer-kumar</a>
Online chemistry magazine with news content which includes ethics cases	<a href="https://www.chemistryworld.com/">https://www.chemistryworld.com/</a>

Examples for connecting elements to cases include the following: Strontium (element 39, group 2) could be discussed along with concepts in ethics and nuclear chemistry, specifically, balancing benefits and risks in various settings (medicine, war) and the careful use of mitigation to minimize harm(10). Carbon (element 6, group 14) could be discussed in the context of the ethics of the Pheramor dating app (<https://www.pheramor.com/>), specifically exploring how the concepts of sincerity, genuineness, soundness and evidenced-based science thread among marketing of “health” and social apps. Silver (element 47, group 11) could be discussed in the context of the ethical complexity of silver nanoparticles, raising concerns about regulations and authorized use (medical use in hospitals vs personal use in socks)(11). Manganese (element 25, group 7) could be discussed in the context of the improperly formulated metal storage vats of the 1919 catastrophic molasses flood, along with the concepts of reliability and professionalism (a synonym for *manners*)(12). The level of complexity of cases and concepts should be steered by the teacher during curriculum development so as to match the learning environment (secondary vs higher education).

### Why Bring Ethics to Chemistry?

The European Chemical Society established the Working Party on Ethics in Chemistry(13) with objectives that include increasing the awareness of the moral complexity of chemistry activities(14). More specifically, they view the ethical issues as crossing several domains, including good scientific practice, publishing, chemical safety (inside and outside the laboratory), chemical synthesis, education, mentoring, and sustainability(14). Other issues in chemistry include professionalism(15,16) and dual use technologies(11).

The ALL European Academies Permanent Working Group on Science and Ethics argued in their statement on *Ethics Education in Science*(17), that ethics education should include the ethical aspects of how society interconnects with science. Education about the ethical connections in chemistry has also been promoted by others(18). Yet while the Working Group’s focus is the university setting, it seems appropriate to begin these discussions prior to university, where early learners are

forming their attitudes, values, and behaviors.

Indeed, the many examples of ethics cases illustrate there are frequent possibilities for ethical dilemmas in the field of chemistry. Memorization of element symbols, atomic numbers and atomic mass, are devoid of the innate contextual connection of chemistry to society, and the ethical matters therein. The use of the PETE in chemistry education is a potential tool for luminating the connection and facilitating discussion and deconstruction. When students make links to real world cases, this can help chemistry seem real and alive, and there is support for this ethics teaching method among chemistry educators(19). For the students who become scientists, “[they] have an obligation to further the conversation about the implications of their work, because they possess more information about the advances that create these ethical questions”(20:59).

A potential limitation of this work is that the ethics words chosen for the PETE table are generally positive or neutral, rather than negative. For example, element 87 (francium, Fr) was assigned the ethics word “FAIR” rather than “FRAUD”. Similarly, element 27 (cobalt, Co) was assigned “COLLEGIAL” rather than “CONFLICT OF INTEREST”. The PETE table is intentionally created with a positive tone to show the beneficent aspects of ethics; however, through case discussions, the negative aspects of ethical dilemmas will also emerge. For example, when discussing element 82 (lead, Pb, group 14, ethics word “publish”) chemistry teachers can include the concept of plagiarism. This notably links to other ethics words in group 14, such as “COURAGE” and “GENUINE”. Another potential limitation of this work is that it has not been formally studied as a curriculum tool. It is hoped that the publication of PETE in open-access form will encourage teachers to use it and assess its value with empirical research methods.

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## References

1. Steele A. Troubling STEM: Making a case for an ethics/STEM partnership. *Journal of Science Teacher Education* 2016; 27(4): 357-371.
2. United Nations Educational, Scientific and Cultural Organization. 2019 IYPT International Year of the Periodic Table of Chemical Elements Opening Ceremony. Paris, France. January 2019. Available from: [https://en.unesco.org/sites/default/files/iypt2019-programme-opening\\_en.pdf](https://en.unesco.org/sites/default/files/iypt2019-programme-opening_en.pdf) Accessed 10 April 2019.
3. Kaji M. Social background of the discovery and the reception of the periodic law of the elements: recognizing the contributions of Dmitri Ivanovich Mendeleev and Julius Lothar Meyer. *Annals of the New York Academy of Sciences* 2003; 988: 302-306.
4. IUPAC | International Union of Pure and Applied Chemistry. *IUPAC Periodic Table of the Elements*; 2018. Available from: <https://iupac.org/what-we-do/periodic-table-of-elements/#a9> Accessed 10 April 2019.
5. Yan X, Lv S, Guo R. Retraction: A New Indicator for Potassium Ions at Physiological pH by Using a Macrocyclic Luminescent Metal Complex. *Chemistry: A European Journal* 2013; 19(19): 5783.
6. National Aeronautics and Space Administration. *Aviation Safety Reporting System: Confidentiality and Incentives to Report*. Available from: <https://asrs.arc.nasa.gov/overview/confidentiality.html> Access 1 June 2019.
7. Woollard J. Overcoming the challenges of legacy mines in the Northern Territory. *AUSIMM Bulletin* 2014; 3: 55-56.
8. Fisher ER, Levinger NE. A directed framework for integrating ethics into chemistry curricula and programs using real and fictional case studies. *Journal of Chemical Education* 2008; 85(6): 796-801.
9. Coppola BP. Targeting entry points for ethics in chemistry teaching and learning. *Journal of Chemical Education* 2000; 77(11): 1506-1511.
10. Mast L. *Meet Katsuko Saruhashi, a resilient geochemist who detected nuclear fallout in the Pacific*; 2019. Available from: <https://massivesci.com/articles/katsuko-saruhashi-geochemistry-seawater-japan/> Accessed 10 April 2019.
11. Calderón-Jiménez B, Johnson ME, Montoro Bustos AR, et al. Silver nanoparticles: Technological advances, societal impacts, and metrological challenges. *Frontiers in Chemistry* 2017; 5: 6 Published 2017 Feb 21. doi:10.3389/fchem.2017.00006.
12. Rossow MP. *The Molasses Flood of 1919 and Other Ethical Failures in Engineering*; 2015. Available from: <https://pdhonline.com/courses/r151/Molasses%20flood%20Study%20Guide.pdf> Accessed 10 April 2019.
13. European Chemical Society. *Statutes*; 2016. Available from: <https://www.euchems.eu/wp-content/uploads/2017/10/Statutes-WP-on-Ethics.pdf> Accessed 10 April 2019.
14. Mehlich J, Moser F, Van Tiggelen B, et al. The ethical and social dimensions of chemistry: reflections, considerations, and clarifications. *Chemistry: A European Journal* 2017; 23: 1210-1218.
15. Kovac J. Ethics in science: The unique consequences of chemistry. *Accountability in Research* 2015; 22(6): 312-329.
16. Tragger R. Chemistry graduate student gets seven years for poisoning co-worker. *Chemistry World*, 13 December 2018. Available from: <https://www.chemistryworld.com/news/chemistry-graduate-student-gets-seven-years-for-poisoning-co-worker/3009898.article> Accessed 10 April 2019.
17. ALL European Academies Permanent Working Group on Science and Ethics. *Ethics Education in Science*; 2013. Available from: [https://www.alllea.org/wp-content/uploads/2015/07/Statement\\_Ethics\\_Edu\\_web\\_final\\_2013\\_10\\_10.pdf](https://www.alllea.org/wp-content/uploads/2015/07/Statement_Ethics_Edu_web_final_2013_10_10.pdf) Accessed 10 April 2019.
18. Köster V, Mehlich J. Bringing ethics in chemistry to universities. *ChemViews* 2018, 4 September. DOI: 10.1002/chemv.201800076
19. Kovac J. Scientific ethics in chemical education. *Journal of Chemical Education* 1996; 73(10): 926-928.
20. Wright MB. The role of ethics in stem education: A course proposal (Honor's thesis, Baylor University, Houston, TX, USA); 2017. Available from: <https://baylor-ir.tdl.org/handle/2104/9974> Accessed 10 April 2019.

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